A Preliminary Results of Site-Specific Ground Response Analysis of Banda Aceh, Indonesia

[1]Bambang Setiawan, [1]Taufiq Saidi

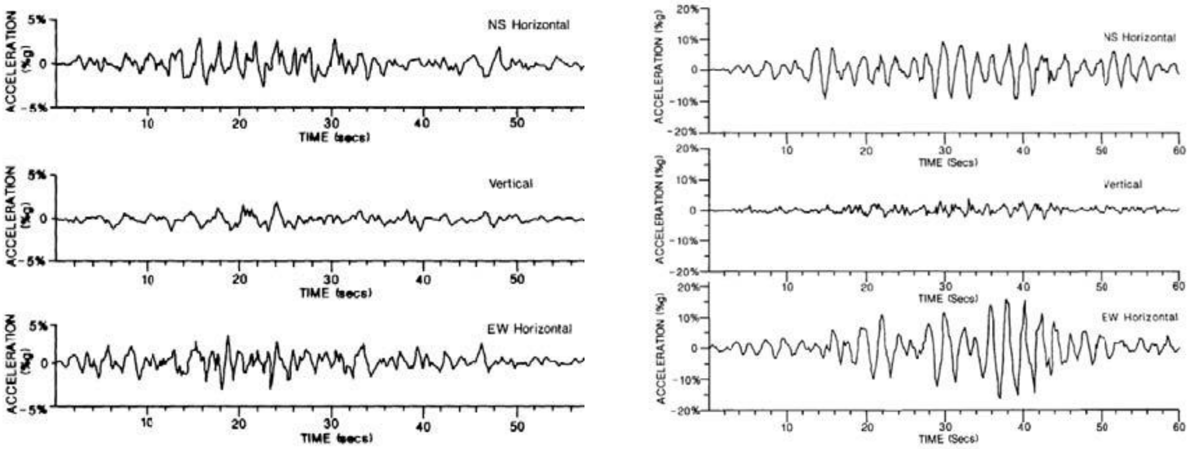
[1]Department of Civil Engineering, Faculty of Engineering, Syiah Kuala University, Banda Aceh 23111. Corresponding Author: bambang.setiawan@unsyiah.ac.id

Abstract. The Mexico City experience in 1985 demonstrated the importance of site response effects. The site response effect i.e. soil amplification has caused major structure damages founded on thick soft soils. Banda Aceh, Indonesia founded on a formation which can be, typically, similar with the Mexico City. The city is underlain by approximately 70m to 206m thick alluvium. Thus, site-specific ground response analysis is necessary to be carried out to establish the most influential parameter i.e. peak ground acceleration and the spectral fundamental frequency. This ground response analysis was carried out using computer program which is *EERA*. This analytical analysis has proven able to depict seismic wave behaviour in soft local soil deposits The results of the site-specific ground response studies are expose the real Banda Aceh's soil response during the 2004 Sumatran mega earthquake. Peak ground acceleration at soil site, the response spectra and fundamental frequency of the maximum response spectra are presented.
Keywords: Soil amplification, ground response analysis, PGA.

Introduction

The 1985 Mexico City earthquake is the extreme evidence of the site response effects. The peak ground acceleration (*PGA*) of the incoming motions in rock during the Michoacan earthquake of generally less than 0.04 *g* were amplified about five times (Finn & Wightman, 2003) and the quake caused severe damage to structures in the area sited on 30m old lakebed deposits. The different of the ground motions of both within the lakebed site and in the rock site are shown in Figures 1a and 1b. The ground motions show that the horizontal North-South (NS) ground motion and East-West (EW) ground motion are very much larger at the lakebed site than at the rock site. Furthermore, Steedman *et al.*, (1986) and Booth *et al.*, (1986) found that the period of the ground motion at the most severe damage area (lakebed deposit) approximately matches with the first mode of the high rise buildings as shown in the corresponding response spectra (Figure 2a). The figure shows clearly the dramatically amplification of lakebed ground surface motion a frequency of 0.5Hz i.e. at a fundamental period of 2 seconds. Figure 2b shows the collapse building at the lake bed area.

In addition, in the 1989 Loma Prieta earthquake, major damage occurred on soft soil sites in the San Francisco–Oakland region where the spectral accelerations were amplified from two to four times over adjacent rock sites (Housner 1989 cited by Finn & Wightman 2003). This soil amplification phenomenon also has been exposed by Idriss (1999) as shown in Figure 3. Idriss (1990) found that the bedrock accelerations were amplified in soft soils until the peak rock acceleration reached about 0.4 *g.*



(a) (b)

Figure 1. (a) Ground surface motion records recorded at rock site and (b) at lakebed site (Booth *et al.*, 1986).

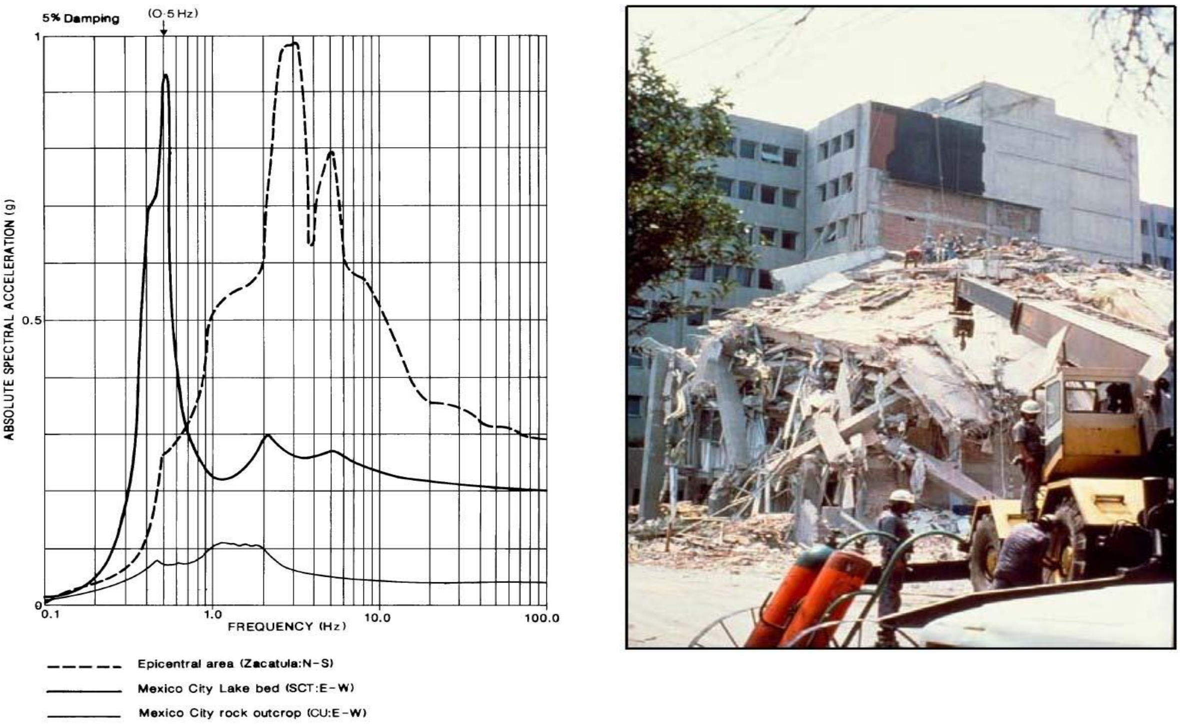


Figure 2. (a) Response spectra of recorded ground motions (b) Example of building collapse (Booth *et al.*, 1986).

Site-specific ground response effects vary significantly in soil properties and the geological setting. Banda Aceh is underlain by approximately 70m to 206m thick alluvium (Siemon et. al., 2006) which is, generally, exhibit similar response effect with the Mexico City. Thus, this research is carried out.

Preliminary findings of this research are presented in this paper. The findings include the ground motion at soil level, the amplification, and response spectra.

Maerials and Methods

Computer program, called *EERA*, was employed in this study. In the site-specific ground response analysis using *EERA*, a sequence of steps (Figure 4) is followed to interpret the earthquake motions in the stable ground surface or bedrock to account for their effects on the soil profile at any specific site. The first step is site characterisation, which involves in-situ testing, soil sampling and laboratory testing. The output of the site characterisation process is a simplified soil profile which represents the designated site. Simultaneously with the site characterisation, the earthquake's motions are manipulated to suit the input format of the computer programs. Both the simplified soil profile and compatible earthquake motions are used as input to the program during ground responses.

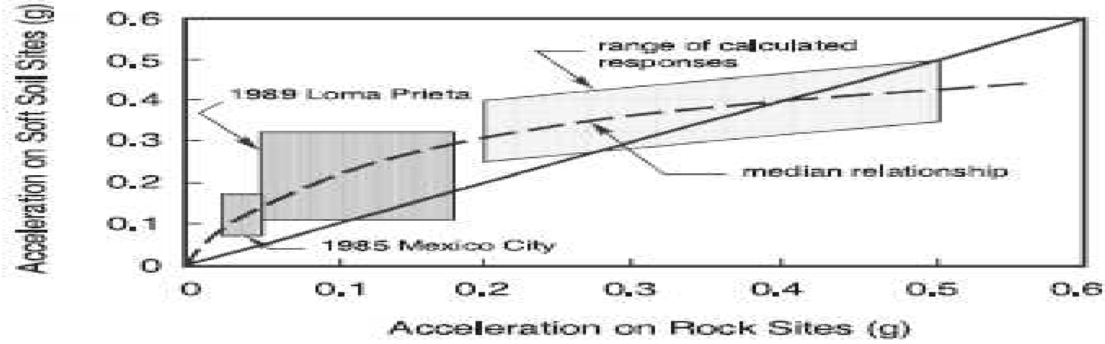


Figure 3. Amplification of ground motions in soft soils and associated rock sites (Idriss, 1990).

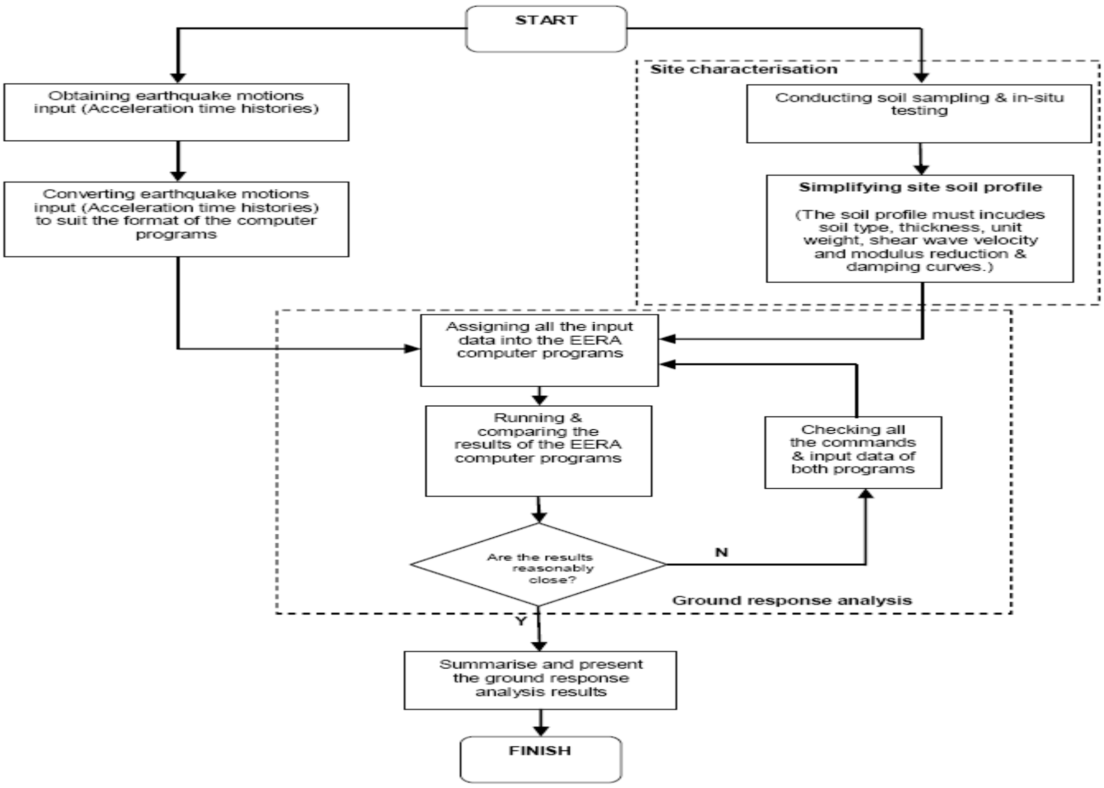
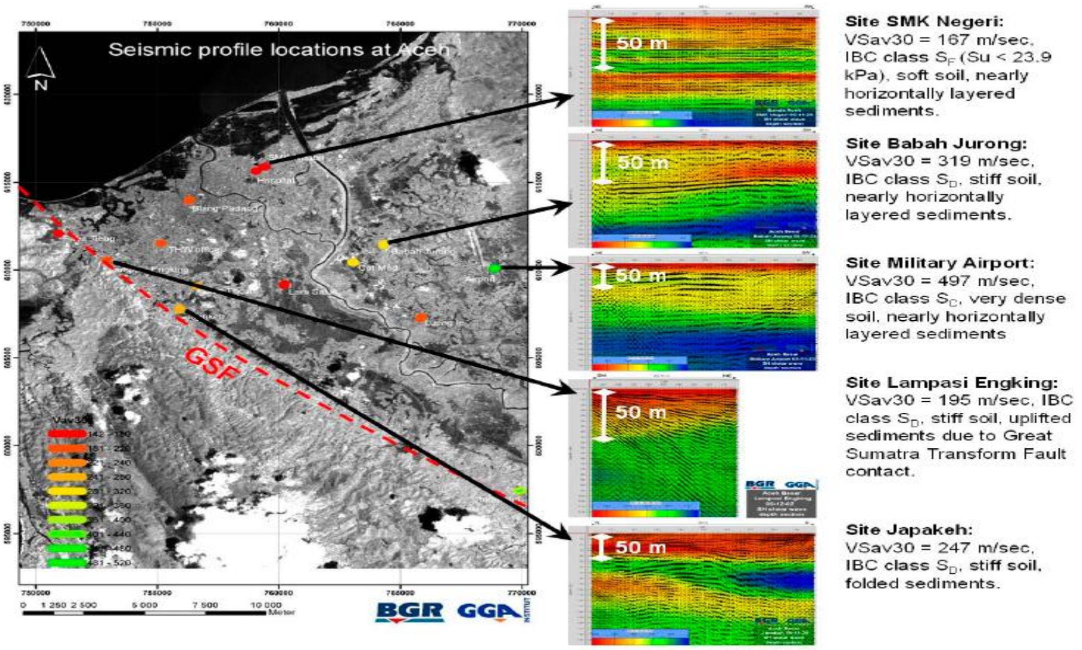


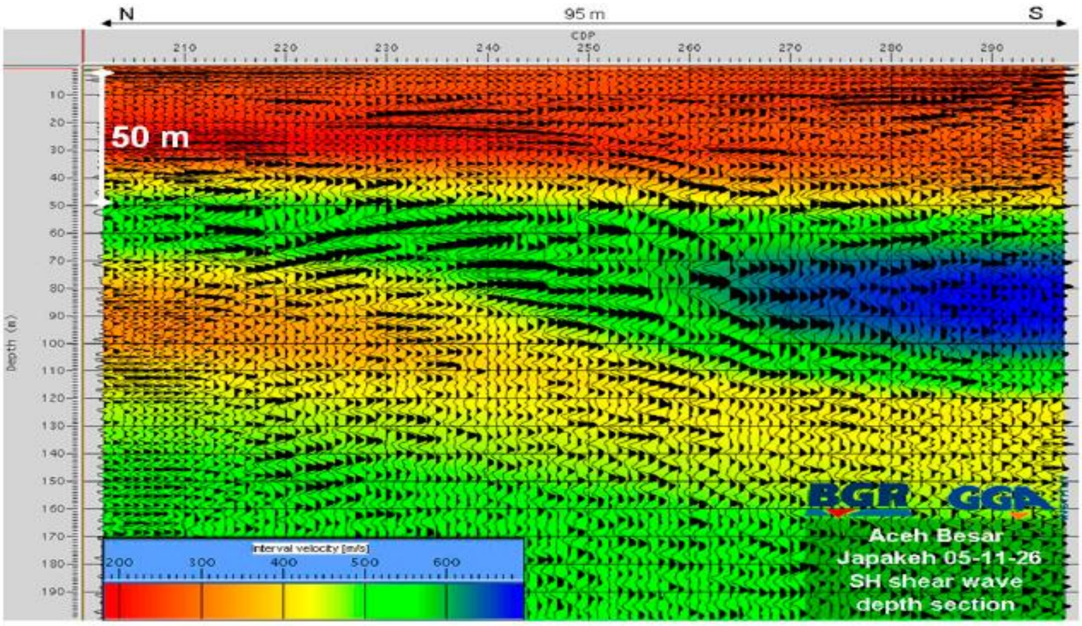
Figure 4. Sequence of steps for site-specific ground response analysis

Characterisation of the site

Site characterisation is based on the results of the soil sampling and in-situ testing by Siemon *et al.*, (2006) and Polom *et al.*, (2008) at Banda Aceh. Profiling of the sub-surface was developed from the study by Siemon *et al.*, (2006) and the shear wave of each layer was estimated using Polom *et al.*, (2008). Shear wave in-situ testing by Polom *et al.*, (2008) is shown in Figure 5. Then a simplified representative soil profile was selected for the analysis as shown in Table 1. This simplified soil profile described the soil type, its unit weight and its thickness.



(a)



(b)

Figure 5. (a) Banda Aceh and surrounding area shear wave velocity and (b) Shear wave velocity profile at SMK – Dirmutala Stadium, Banda Aceh (Polom *et al.*, 2008).

Table 1. Simplified soil profile for EERA.

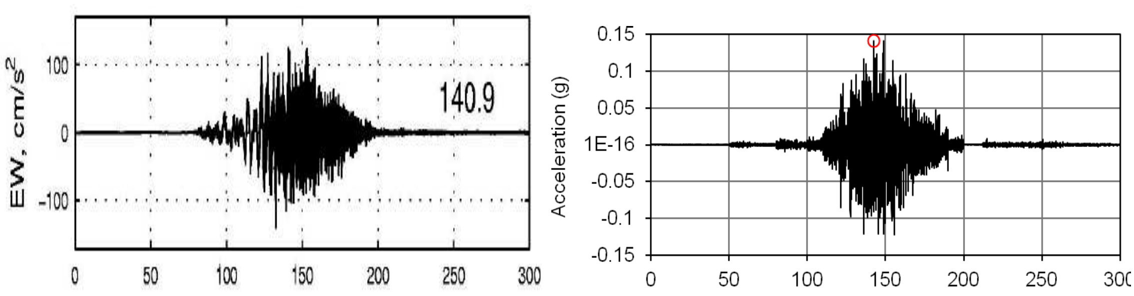
Note	Layer Number	Soil Material Type	Thickness of layer (m)	Total unit weight (kN/m^3)	Shear wave velocity (m/sec)	References
	1	Clay	2.5	14	142	Siemon *et al.*, (2006) and Polom *et al.*, (2008)
	2	Sand	15.5	19	142	
	3	Clay	7.7	14	281	
	4	Sand	6.0	19	361	
	5	Clay	18.6	14	361	
	6	Sand	14.3	19	361	
	7	Clay	11.3	18	361	
	8	Sand	4.0	24	361	
	9	Clay	1.1	20	331	
	10	Sand	40.0	24	331	
	11	Sand	20.0	24	401	
	12	Sand	15.0	24	520	
	13	Sand	15.0	24	520	
Bedrock	14	3		24	700	

Modulus reduction and damping curves

Ideally for a site-specific ground response analysis, the modulus reduction and damping curves are obtained according to the soil profile. As there is no access to a controlled cyclic triaxial apparatus for this research, the default shear modulus-strain and damping ratio-strain curves in *EERA* are used. These default curves have proven to work well in most applications for site-specific ground response analysis (Sykora & Davis, 1993; Uthayakumar & Naesgaard, 2004). Each curve represents a unique behaviour of the shear modulus and damping ratio during strain.

Earthquake motion input

It is advantageous to use actual acceleration time-histories that have been recorded at the study site or use recorded motions that are somewhat similar in overall ground motion level and spectral shape to those at the designated site. However, compromises are required in this study because of the numerous attributes of the seismic environment. Simulated motion input was used in this study as shown in Figure 6b.



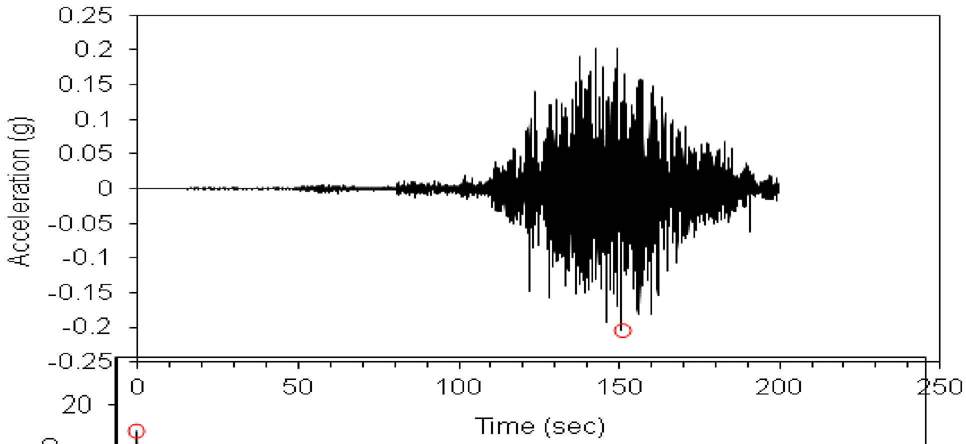
(a) (b)

Figure 6: (a) Simulated strong ground motions for the great Sumatra-Andaman earthquake at Banda Aceh (Sorensen *et al.*, 2006); (b) Banda Aceh simulated strong ground motions for this study.

Results and Discussion

The site-specific ground response analysis

The site-specific ground response analysis yielded the following: peak ground acceleration; stress and strain at each layer; amplification at the ground surface or the surface of each layer; Fourier amplitude; and the response spectrum. Three important outputs from the ground response analysis are shown in Figures 7 to 9.



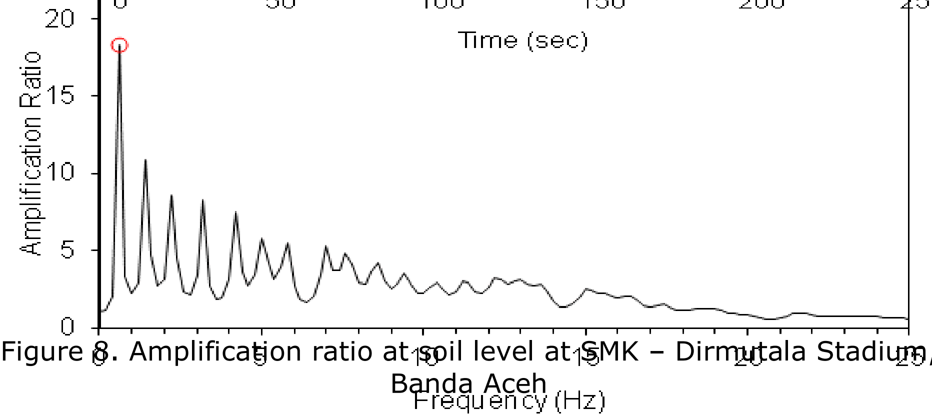


Figure 8. Amplification ratio at soil level at SMK – Dirmutala Stadium, Banda Aceh

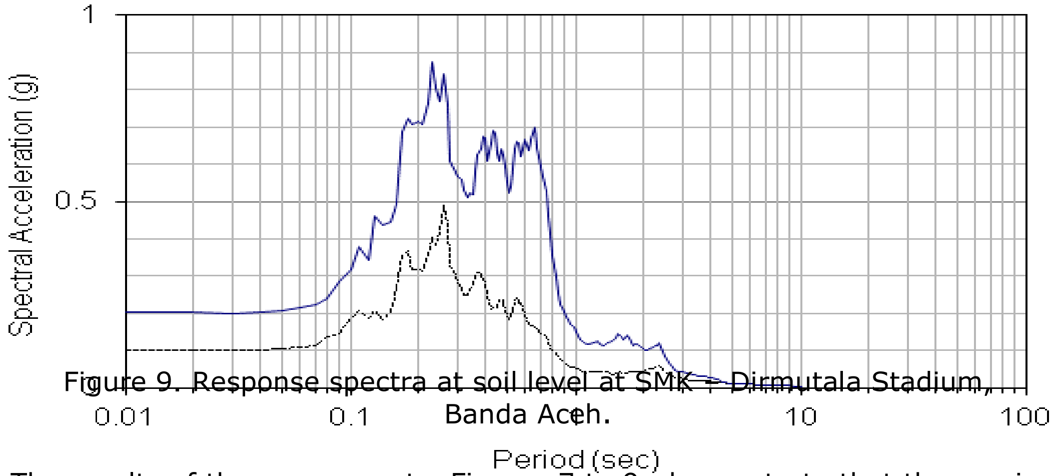


Figure 9. Response spectra at soil level at SMK – Dirmutala Stadium, Banda Aceh.

The results of the assessments, Figures 7 to 9, demonstrate that the maximum PGA at SMK – Dirmutala Stadium is 0.204g and the absolute response spectra at period of 0.2sec is 0.71g. The maximum absolute response spectra, 0.87g, is at period of 0.23sec. The response spectra suggested a good agreement with the latest Indonesian earthquake map as shown in Figure 10. In this map, Banda Aceh's PGA varies from 0.7 to 0.9g. The frequency domain of the response spectra of Banda Aceh's soil shows that the critical frequency at Banda Aceh is between 2.0 to 8.0Hz as shown in Figure 11. This frequency is the frequency of the ground motion at epicentral area of the Michoacan earthquake. Generally, the frequency between 2.0 and 8.0Hz is the fundamental frequency of 2 to 4 storey building.

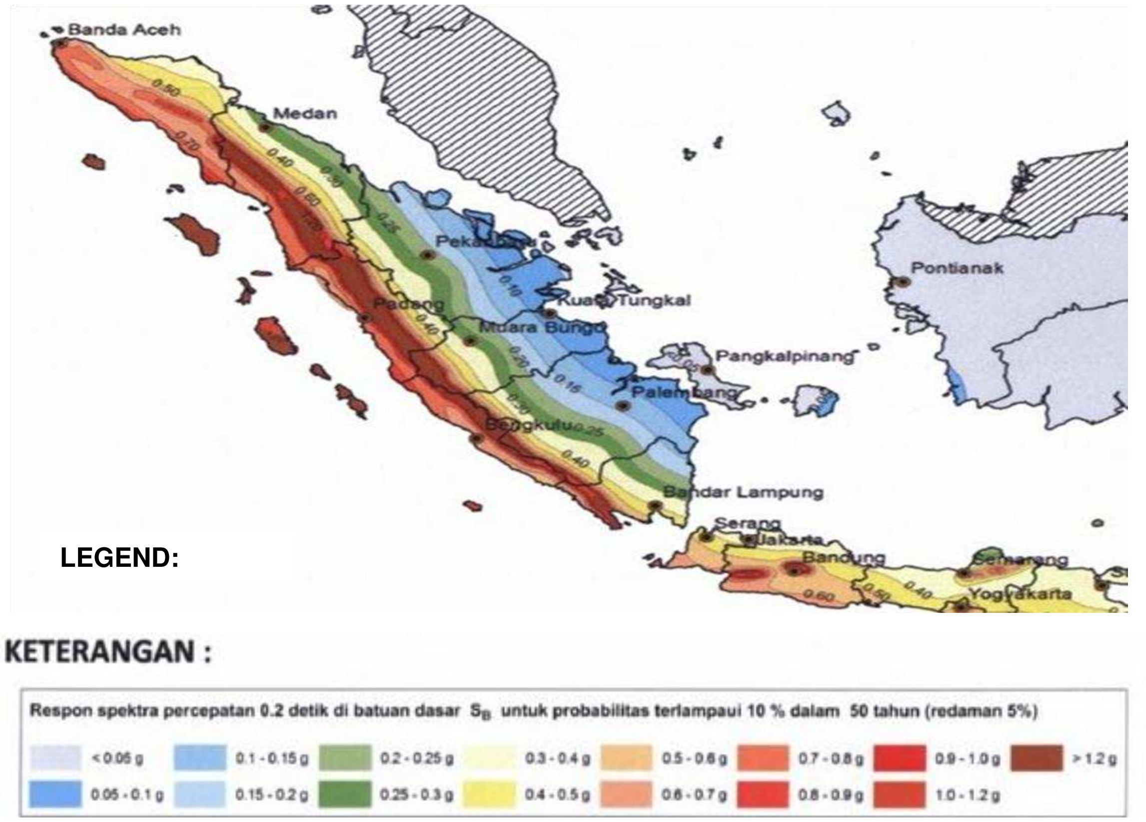


Figure 10. Part of 2010 Indonesian earthquake map

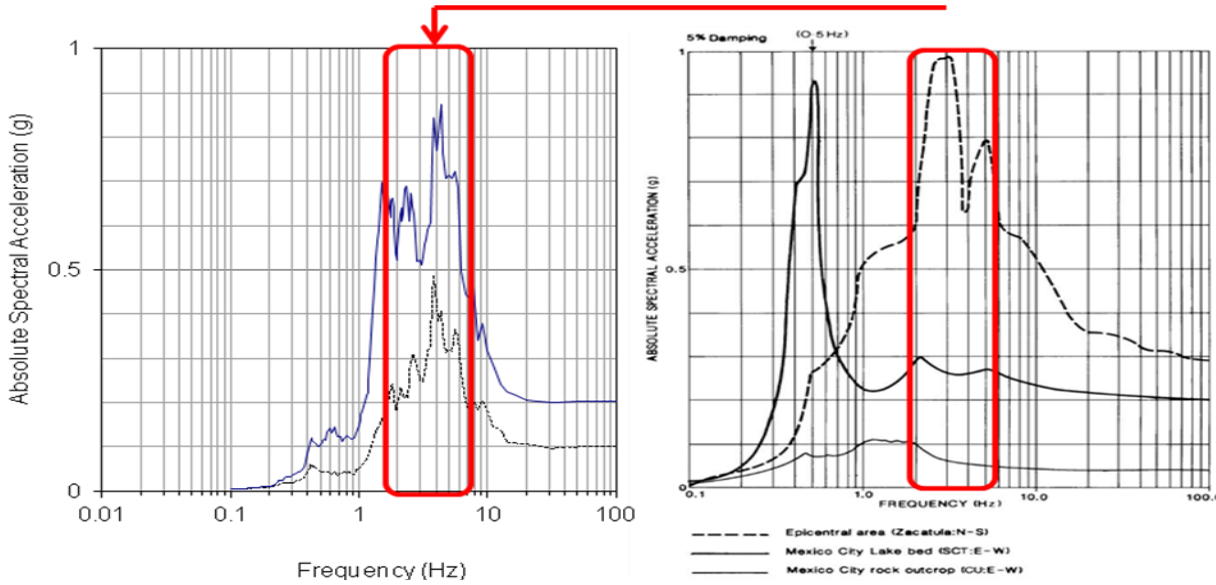


Figure 11. Frequency domain of response spectra at soil level at SMK – Dirmutala Stadium, Banda Aceh

Conclusions

The site response effect has caused major structure damages founded on thick soft soils such as Banda Aceh, Indonesia. The city is underlain by approximately 70m to 206m thick alluvium. Site-specific ground response analysis of the city was carried out to establish the most influential parameter i.e. peak ground acceleration and the spectral fundamental frequency. This ground response analysis was carried out using EERA computer program. The results of the site-specific ground response studies are expose the real Banda Aceh's soil response during the 2004 Sumatran mega earthquake. Peak ground acceleration at soil site at Banda Aceh is 0.209g. The response spectrum at period of 0.2 sec is 0.71g. Fundamental frequency of maximum response spectra varies from 2.0 to 8.0Hz.

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